

Exhaust Emission Factors for Nonroad Engine Modeling-- Spark Ignition

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Purpose

This report describes and documents exhaust emission factors used for spark ignition (SI) engines in EPA's NONROAD emission inventory model. It covers emission factors for engines powered by gasoline, natural gas and liquefied petroleum gas.

EPA expects to recalculate most SI emission factors prior to release of the final version of the NONROAD model. This report describes the emission factors that will be used for the beta version of the model and lists the data sources that will be considered when calculating new emission factors for the final model. When complete, the final emission factors will be similarly documented and distributed for stakeholder review.

Emission factors for compression ignition (diesel) engines are covered in a separate report, (NR-009). Additional EPA reports will describe other issues relating to emission factors including NONROAD emission factors for evaporative emissions, crankcase emissions, spillage and other non-exhaust emissions (NR-012), adjustments to emission rates due to variations in fuel and temperature (NR-001), and adjustments to emission rates as equipment deteriorates due to time and use (NR-011).

Introduction

The U.S. EPA's NONROAD model computes county-level emission inventories for nonroad engines. These calculations rely on emission factors--estimates of the amount of pollution emitted by a particular type of equipment during a unit of use. Typically emission factors for nonroad sources are reported in grams per horsepower-hour, but they also may be reported in grams per mile, grams per hour, grams per gallon, etc.

This report begins by describing emission factors used in prior models. It then briefly describes our plans for pre-controlled and controlled SI exhaust emission factors in the beta and final versions of NONROAD.

Appendix A provides information on the sources of emission factors. Appendix B has two parts: (1) a large spreadsheet that lists the numerical value of emission factors that have been

used in prior inventories and that we intend to use for the beta version of NONROAD, and (2) a guide to using the spreadsheet. Appendix C explains how NONROAD uses “technology groups” to account for changes in emission factors over time.

As explained in NR-006, spark-ignition engine equipment population under 25 horsepower will be combined into one SCC per application to handle expected shifts in market share between 2 and 4-stroke gasoline, LPG, and CNG engines. In the model, the distinction between two- and four-stroke spark-ignition engine emission factors will be maintained using the technology groups described in Appendix C of this report. In this current document, the SCC distinction between 2 and 4-stroke gasoline, LPG, and CNG engines is maintained, however, in the model, we will distinguish emission factors between them by using the technology group methodology.

Background

Prior to the NONROAD model, there have been three major efforts to estimate nonroad spark ignition emission inventories. We have relied heavily on these efforts in our work to select emission factors for the beta version of NONROAD. The three inventories/models are:

- EPA’s Nonroad Engine and Vehicle Emission Study (“NEVES”).[1] Published in November, 1991, this study was mandated by Congress to determine whether nonroad sources made a significant contribution to urban air pollution. The study covers emissions from all nonroad engines and includes hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), total particulates (PM), sulfur dioxide (SO₂) and other pollutants. It provides inventories for 19 ozone and 16 CO nonattainment areas.
- California Air Resources Board’s nonroad model (“OFF-ROAD”) [2], designed to estimate nonroad emissions for the state of California only. A beta version of this model was released August 1, 1997. The model covers HC, CO, NO_x, PM, sulfur dioxide (SO₂), and carbon dioxide (CO₂) for all nonroad engines. ARB is currently revising much of its work on nonroad modeling and the emission factors reported here may not reflect ARB’s most recent conclusions.
- EPA’s “Small Engine Model”--designed as an internal tool for evaluating various control scenarios, EPA has used this model to estimate the effect of regulations on small spark-ignition (SI) engines under 19 kW (25 hp) This model has evolved over time, but the pre-control exhaust emission factors have not changed since the model was documented in 1995.[3] The model computes national-level inventories of nonroad HC, CO and NO_x.

As detailed in Appendix A, the emission factors used in these prior efforts have been based on a very small number of engine studies, particularly when compared to the large body of data available for highway vehicles.

Emission Factor Categories

NEVES defines emission factors by the equipment use (i.e., by “application”) but does not assign different emission factors to engines of different sizes within the same application. On the other hand, OFF-ROAD and the Small Engine Model define emission factors by engine size (by horsepower in OFF-ROAD and by displacement in the Small Engine Model), but do not assign different emission factors to engines used in different applications that are of the same size. Given the structure of emission control regulations and the design similarities between engines of the same horsepower used in various applications, we will likely define emission factors primarily by power level for the final release of NONROAD. The NONROAD model allows for the use of application-specific emission factors if there is sufficient information to justify their use by the time of the final release. We expect to use application-based emission factor categories only to distinguish handheld equipment, recreational marine engines and selected recreational vehicles.

Due to time and resource constraints, inputs for the beta version of NONROAD will retain some of the application-specific groupings given by NEVES and the Small Engine Model as detailed below. However, we intend to recalculate emission factors for the final version of the model based on the information given in Appendix A.

Accounting for In-Use Operation

Many nonroad engines operate under transient loads, but the engines are typically tested with steady-state tests. While clear and significant differences between in-use transient and steady-state emissions have been found for compression-ignition engines, such differences have not been found conclusively for SI engines. Three studies have compared transient and steady-state emissions in SI engines, but they have not found consistent results. [4-6] At present, EPA believes there is not sufficient information to justify an in-use transient adjustment factor for SI engines, so the NONROAD model will use emission factors based on unadjusted steady-state test results.

Emission Factors for Pre-control Engines--Beta Version

This section describes the emission factors that will be used for the beta version of NONROAD. Because we plan to recalculate the pre-control emission factors for the final version of the model, these emission factors should be considered placeholder values.

Gasoline Engines ≤ 25 hp

In general, for small gasoline engines, the beta version of the model will use emission factors based on those in the Small Engine Model.[7] Like the Small Engine Model, NONROAD will distinguish between handheld and non-handheld applications and distinguish

engines by size. The beta version of NONROAD will not separate overhead valve and side-valve four-stroke engines, but will combine these Small Engine Model emission factors into single factors by applying the Small Engine Model's sales weightings (see Appendix A and B).

Gasoline engines > 25 hp

For larger gasoline engines, the beta version of the model will use emission factors from NEVES. However, to simplify the entry of these placeholder values, and to move toward the horsepower-based emission factors planned for the final version of the model, the beta version of the inputs will not distinguish emission factors for specific applications such as "rubber-tired dozer", but instead will use a single factor for all equipment in a general category such as "construction" or "agriculture". Table 1 lists the specific NEVES emission factors to be used for large engines in the beta version of NONROAD.

Table 1-- NEVES sources of NONROAD large engine emission factors

Emissions Category in NONROAD (Beta Version)	Based on NEVES Emission Factors for:
-All Construction > 25 hp	"Other Construction Equipment"
-All Industrial >25 hp -All Lawn & Garden > 25 hp -All Commercial >25 hp -All Logging > 25 hp -All Aircraft Support > 25 hp -All Underground Mining >25 hp -All Oil Field Equipment > 25 hp	"Other General Industrial Equipment"
-All Agricultural >25 hp	"Other Agricultural Equipment"

NEVES used one average power level and one average emission factor for each application. NEVES used emission factors from AP-42 which were calculated for the average power level of each specific application. The beta version of the NONROAD model will account for power level by using small and large engine emission factors for each application. We expect this approach will provide results similar to NEVES and will serve as an acceptable placeholder until new factors are calculated.

Recreational Marine Engines

Emission factors for recreational marine spark-ignition engines were taken from work accomplished in support of the rulemaking for new emission standards for these engines. [8] The emission rates for the precontrolled engines are listed below. Because the initial emission factor investigation was primarily interested providing the best overall estimate, some power level groupings were determined to be less significant and do not exactly match the power levels

used in NONROAD. The tables below show the emission factors by power level in the original work and what are used in the beta version.

Table 2 Two-Stroke Outboard (SCC - 2282005010) Emission Factors for Precontrolled Engines

EPA- RIA	Beta Version for NONROAD	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
<3.9 hp	0 - 3 hp	336	2.4	505
3.9 - 9.9	3 - 11	329	1.5	571
9.9 - 29.9	11 - 25	185	1.6	462
29.9 - 49.9	25 - 50	140	2.2	298
49.9 - 74.9	-----	150	2.4	299
74.9 - 99.9	50 - 100	155	2.2	332
99.9 - 149.9	-----	152	1.7	338
149.9 - 199.9	100 - 175	150	1.7	380
>199.9	>175	165	1.4	378

Table 3 Four-Stroke Outboard (SCC - 2282005010) Emission Factors for Precontrolled Engines

EPA- RIA	Beta Version for NONROAD	HC (g/kW-hr)	NOx (g/kW-hr)	CO (g/kW-hr)
<3.9 hp	0 - 3 hp	47.0	8.7	380
3.9 - 9.9	3 - 11	28.3	5.7	300
9.9 - 29.9	11 - 25	15.6	6.5	280
29.9 - 49.9	25 - 50	10.9	10.2	250
49.9 - 74.9	-----	8.4	11.3	250
74.9 - 99.9	50 - 100	14.5	9.2	225
99.9 - 149.9	-----	11.1	11.2	225
149.9 - 199.9	100 - 175	15.0	6.5	200
>199.9	>175	15.0	6.5	200

Table 4 Personal Watercraft (SCC - 2282005015) Precontrolled Emission Factors

EPA- RIA	Beta Version for NONROAD	HC (g/kW-hr)	NO _x (g/kW-hr)	CO (g/kW-hr)
30 - 50 hp	16 - 25 hp	181 (2-stroke) 15.6 (4-stroke)*	0.95 (2-stroke) 6.5 (4-stroke)*	346 (2-stroke) 280 (4-stroke)*
	25 - 50	181	0.95	346
50 - 75	50 - 175	206	1.37	339

* Taken from the 4-stroke Outboard Emission Factors

Table 5 Inboard (SCC - 2282010005) Precontrolled Emission Factors

EPA- RIA	Beta Version for NONROAD	HC (g/kW-hr)	NO _x (g/kW-hr)	CO (g/kW-hr)
100 - 150 hp	25 - 100 hp	7.2	7.6	175
150 - 200	100 - 175	7.0	7.6	175
>200	>175	5.4	10.4	174

Motorcycles, All-Terrain Vehicles (ATVs), and Snowmobiles

Because these engines differ significantly from other SI engines, the beta version of the model will use the emission factors used in NEVES. These emission factors are the same as used by the OFFROAD model, and the Small Engine Model does not consider these applications.

Natural Gas/LPG Engines

For engines fueled by natural gas and Liquefied Petroleum Gas (LPG), the beta version of NONROAD will use the emission factors used in NEVES because these are the only estimates for which full documentation is available.

Emission Factors for Pre-control Engines--Final Model

For the final version of the model, EPA plans to recompute emission factors for pre-control engines. The new factors will be based on data described in Appendix A. This data includes confidential data from manufacturers and baseline data from a number of small studies. EPA requests immediate assistance in identifying additional sources of pre-control emissions data and assistance in obtaining raw data for the studies listed. Raw data is needed to demonstrate that the emissions information is aggregated properly.

EPA also requests comment on whether the final version of the model should distinguish overhead valve and side-valve four-stroke engines or other technology types with unique emission factors, and on the sources of data that could be used to estimate such emission factors.

Controlled Emissions--Beta and Final

In addition to estimating emissions from pre-controlled engines, the NONROAD model is designed to account for the effect of federal emissions standards. The model does not cover California emission standards and federal standards that are not yet final. However, because EPA expects to finalize the proposed Phase 2 small engine rule before the release of the final NONROAD model, the proposed Phase 2 standards have been included in the beta version of the model. Thus, NONROAD will include emission factors under three regulations:

- Emissions for New Nonroad Spark Ignition Engines at or below 19 Kilowatts. (“Small Engine Rule, Phase I”) [9]
- Phase 2: Emission Standards for New Nonroad Spark-Ignition Engines At or Below 19 Kilowatts “Small Engine Rule Phase II” [10]
- Final Rule for New Gasoline Spark-Ignition Marine Engines; Exemptions for New Nonroad Compression-Ignition engines at or Above 37 Kilowatts and New Nonroad Spark-Ignition Engines at or Below 19 Kilowatts (“Marine Rule”) [11]

NONROAD will use the brake-specific fuel consumption (BSFC) and the HC, CO, and NO_x emission factors that are in the regulatory support documents for the rules listed above. The NONROAD input structure for handling the phase-in of new emission standards and technologies is explained in Appendix C. The control emission factors for marine engines are listed in the spreadsheet Tech1.wk4 and the technology fractions are listed in the workbook Technmix.wk4. The Phase I and Phase II emission factors for small SI engines are from Appendix F of the Phase II regulatory support document. The emission factors for Phase I and Phase II engines are listed as “new engine exhaust” values in Table F-07. NONROAD’s technology fractions for these engines will follow the sales mixes for Phase I and Phase II as listed in Tables F-03 and F-04 of the RSD appendix. If changes are made to the Phase II final rule, the final version of the model will reflect those changes.

In the future, EPA will consider using certification data to determine emission factors for small engines and marine engines subject to federal regulation.

References

[1] “Nonroad Engine and Vehicle Emission Study” (NEVES), U.S. EPA, Office of Air and Radiation, 21A-2001. November, 1991.

- [2] "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model," ("Inputs...") Energy and Environmental Analysis, Inc. for California Air Resources Board. February, 1997.
- [3] "Documentation of the OMS Small Gasoline Engine Spreadsheet System, Final Technical Memorandum," Dan Bowman, TRC Environmental Corporation. August 1995.
- [4] "Emissions Analysis of Small Utility Engines." Sun, X., et al. SAE paper 952080. 1995.
- [5] "Emissions from 4-Cycle Walk-Behind-Mower Engines: Test Cycle Effects." Gabele, Peter. SAE Paper 972793. 1997
- [6] "Transient versus steady-state test procedure evaluation of 4-cycle utility engines," Carpenter, T., Buszkiewicz, T., Trimble, T. EPA regulation negotiation test procedure task group, November, 1994. EPA Air Docket A-93-29, Docket Item II-M-27.
- [7] "Regulatory Support Document, Control of Air Pollution, Emission Standards for New Nonroad Spark-ignition Engines at or below 19 Kilowatts," U.S. EPA, May 1995, EPA Air Docket, Docket Item # V-B-01.
- [8] "Regulatory Impact Analysis: Control of Air Pollution Emission Standards for New Spark-Ignition Marine Engines," U.S. EPA, October, 1996.
- [9] 60 FR 34581, July 3, 1995.
- [10] "Regulatory Support Document, Phase 2: Emission Standards for New Nonroad Spark Ignition Engines At or Below 19 Kilowatts". U.S. EPA, Office of Air and Radiation, December 1997.
- [11] 61 FR 52087, October 4, 1996.

Appendix A

Detailed Discussion of Pre-Control Emission Factors for Spark Ignition Engines

This appendix provides a detailed description of the data sources used for pre-control emission factors for spark ignition (SI) engines in previous nonroad emission inventories. The Appendix also describes the pre-control emission factors that will be used in the beta version of NONROAD and it lists additional studies that EPA will consider when recalculating pre-control emissions factors for the final version of NONROAD. The appendix is divided into four sections:

- Emission Factors that Apply to All Spark Ignition Engines
- Emission Factors for 2-stroke Gasoline Engines
- Emission Factors for 4-stroke Gasoline Engines
- Emission Factors for Natural Gas/Petroleum Gas Engines

Note: This appendix uses the following abbreviations:

ARB	(California) Air Resources Board
ATV	All-Terrain Vehicle
BSFC	brake-specific fuel consumption
CO	carbon monoxide
CO ₂	carbon dioxide
EEA	Energy and Environmental Analysis, Inc.
EMA	Engine Manufacturers Association
EPA	U.S. Environmental Protection Agency
FC	fuel consumption
HC	hydrocarbons
man.	manufacturers
na	not available
NEVES	(U.S. EPA) Nonroad Engine and Vehicle Emission Study
NMHC	non-methane hydrocarbons
NO _x	nitrogen oxides
OHV	overhead valve
OPEI	Outdoor Power Equipment Institute
PPEMA	Portable Power Equipment Manufacturers Association.
PM	particulate matter
rpm	revolutions per minute
TSD	technical support document
SwRI	Southwest Research Institute
SO ₂	sulfur dioxide
UM	University of Michigan
WBM	walk-behind (lawn) mower

All Spark Ignition Engines

Sulfur Dioxide Emission Factors

Sulfur dioxide emissions are rarely measured. Instead, they typically are calculated from fuel consumption and fuel sulfur content. We have retained this approach for the NONROAD inputs. Sulfur dioxide emission factors for gasoline engines are calculated using the following equation:

$$SO_2 = (BSFC * 453.6 - HC) * 0.00034 * 2$$

where

SO₂ is in g/hp-hr

BSFC is in lb/hp-hr

453.6 is the conversion factor from lbs to g

HC is hydrocarbon emissions in g/hp-hr

0.00034 is the default average wt. fraction of sulfur in gasoline

2 is the grams of SO₂ formed from a gram of sulfur

The calculation for CNG/LPG engines is similar, with an average fuel sulfur content of 0.00003. This equation differs from the equation used for diesel engines in that all the sulfur is assumed to become sulfur dioxide. This may be a simplification because a relatively small fraction of sulfur (roughly 2%) can be converted in the engine to sulfur trioxide. Sulfur trioxide or the particulate derived from sulfur trioxide is not measured from gasoline engines, so there is no basis upon which to determine a sulfur related particulate emission rate. Therefore we ignore the small effect of particulate sulfur for the sulfur dioxide calculation.

The SO₂ emission factors are calculated for NONROAD's input data files based on the default fuel sulfur content listed here. NONROAD users may use the model interface to adjust the fuel sulfur content without changing the input files.

Carbon Dioxide

The NONROAD model does not require emission factors inputs for carbon dioxide. CO₂ emissions are calculated by the model based on fuel consumption.

Fuel Consumption

There are few studies that also measured fuel consumption in nonroad engines. NEVES does not explicitly report fuel consumption, but fuel consumption is reported for selected sources in the NEVES Appendix I. ARB reports fuel consumption and cites two studies: (1) ARB's 4-stroke factors for overhead valve (OHV) engines less than 25 horsepower and for side-valve

engines of all horsepower are from an SwRI report.[1] (2)ARB's fuel consumption factors for OHV 4-stroke gasoline engines greater than 25 horsepower were based on pre-control on-road engine BSFC.[2] The small engine model lists fuel consumption for engines <25 hp, but the source of this estimate is not clear.

EPA intends to improve fuel consumption factors in the final version of the model; however, due to time constraints, the beta version of the model will use BSFC data adapted from that available in NEVES.

Two Stroke Gasoline Engines

Table A1 lists the sources of data used for emission factors of two-stroke engines in previous inventories and planned for the NONROAD beta model. The table also lists studies that provide additional data that EPA will consider when recalculating emission factors for the final version of the model. The references listed in the table are described below.

[1] White, Carroll, Hare and Lourenco. Emission Factors for Small Utility Engines. Southwest Research Institute and California Air Resources Board. 1991. (SAE Paper 910560).

[2] "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model", Energy and Environmental Analysis, Inc., for California Air Resources Board, February, 1997. Appendix A.

Table A1–Data Sources for Baseline Emission Factors for Two-Stroke Gasoline Engines

Equipment Description	Emission Factor Data Sources given in Table A2 and Used by:				Notes	Additional Data Sources
	NEVES	ARB	Small Engine Model	Nonroad Beta Version		
General non-handheld (≥ 3 hp)	A	A,B	A	A	ARB includes a deteriorated engine (B) in PM estimate.	1,2
Offroad Motorcycles ATVs (all hp)	C, ?	C	na	C, ?	It is not clear where NEVES PM estimates are from, but we will use them for beta.	3
Golf carts, Minibikes and Specialty Carts (>3 hp)	C	A,B	A	A	Operating at lower rpm, these engines are more like lawnmowers than motorcycles.	
(≤ 3 hp)	C	G	A	G		
Snowmobiles (all hp)	D	D	na	D		4,5
Outboard marine engines (all hp)	A,E,F	A,E	na	A,E,F	NEVES and ARB use (A) for PM. NEVES uses (F) for SO ₂	6,7
Personal Watercraft (all hp)	na	na	na	9	For beta, calculate HC, CO, NO _x and SO _x from new data. Use BSFC and PM from outboards.	8
Non-handheld (≤ 3 hp)	A	G	A	G		9, 10, 11
Handheld	G	G	G (modified)*	G (modified)*		12-18

* The small engine model documentation states that the emission factors for handheld engines were modified based on manufacturers data.

Table A2—Emission Factor Data Sources Listed in Table A1 for Two-Stroke Gasoline Engines

Reference Code	Number of Engines Tested	Age and Application of Engines	Horsepower of engine	Testing lab	Emissions measured	Citation and notes
A	1	WBM	5 hp	SwRI	HC, CO, NO _x , PM, FC	“Technical Support Document for California Exhaust Emission Standards and Test Procedures for 1994 and Subsequent Model-Year Utility and Lawn and Garden Equipment Engines.” (ARB TSD) California Air Resources Board. Attachment C to ARB Mailout #90-64. December 1990. p. 31. Some of this data also is reported in SAE 910560.
B	1	11-year-old WBM	2.4 hp	SwRI	HC, CO, NO _x , CO ₂ , PM, FC	Carroll, James N. Emission Tests of In-Use Small Utility Engines, Task III Report Non-Road Source Emission Factors SwRI 3426-006 for EPA, September 1991.
C	?	?	?	?	HC, CO, NO _x	ARB Mailout #90-58, “Proposal to control emissions from Off-Road Motorcycles,” September 7, 1990. The mail-out does not describe the source of the emission factors. According to Ingalls, M. “Nonroad Emission Factors, Interim Report” SwRI 08-3426-005. February 1991, for NEVES, the mailout factors were converted to g/hr based on average speed of 25 mph.

D	3	snow-mobiles	?	SwRI	HC, CO, NO _x , PM, FC	AP-42, 4th Edition, Sept. 1985. II-8. Data is based on: C.T. Hare, K.J. Springer, T.A. Huls, "Snowmobile Engine Emissions and Their Impact", SAE 740735, 1974. Converted to g/hp-hr by dividing by an average hp of 5.8.
E	25	outboard engines	?	EMMA	HC, CO, NO _x , BSFC	NEVES
F	4	outboard engines	?	SwRI	HC, CO, NO _x , SO _x	Hare C.T. and K.J. Springer. "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Part II, Outboard Motors. Final Report." Southwest Research Institute. January 1973.
G	50 including legible data on: 8 11 2	 chainsaws chainsaws trimmers	 1-3 hp 3-6 hp 0-1 hp	PPEMA	HC, CO, NO _x	Heiden Report cited in "ARB TSD". The closest in EPA docket is Untitled, A-93-25 II-D-23. Only part of this data is legible. EPA requests assistance locating this report.

Table A3--Known Additional Data Sources Listed in Table A1 for Gasoline Two-Stroke Engines

Reference Code	Number of Engines Tested	Age and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
1	2	?	3, 4.5	UM	HC, CO, NO _x , CO ₂	Sun, X., et al., "Emissions Analysis of Small Utility Engines." SAE paper 952080. 1995.
2	2	7- and 10-year-old mower*	?	UM	HC, CO, NO _x	Charmley, William. "Memorandum: U/M data on in-use two strokes" 1993. (Docket A-93-25/II-B-03)
3	1	moped/ATV	6	SwRI	NMHC, CO, NO _x , PM	Hare, C.T., and J.J. White. "Toward the Environmentally-Friendly Small Engine: Fuel, Lubricant, and Emission Measurement Issues," 1991. SAE 911222 in SAE P-254.
4	8	snowmobile	?	man.	HC+ NO _x , CO	"Regulatory Strategies for Off-Highway Equipment. Addendum: Potential Emission Control Regulations for Snowmobiles, Preliminary Draft" EEA for ARB, February 1992, p. A-12. Data from International Snowmobile Industry Association.
5	1	snowmobile	50 hp	SwRI	HC, CO, NO _x , PM, BSFC	White, Jeff J. et al. "Baseline and Controlled Exhaust Emissions from Off-Highway Vehicle Engines," SAE 931541, (SwRI/ARB 1993) December, 1993.
6	1	outboard marine	9.9 hp	EPA	HC, CO, NO _x , FC	"Memorandum: Exhaust Emission Testing of a Two-Stroke and a Four-Stroke Marine Engine; Results and Procedures," Mike Samulski to Docket #A-92-28.
7	?	outboard marine	?	man.	HC, CO, NO _x	Manufacturer testing of 56 engine families. (Confidential business data.)

8	?	PWC	?	man.	HC, CO, NO _x	Manufacturer testing of 10 engine families (Confidential business data)
9	1	non-handheld	2 hp	SwRI	HC, CO, NO _x , PM	Hare, C.T., K.J. Springer. "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment using Internal Combustion Engines, Final Report Part 4, Small Air-Cooled Spark Ignition Utility Engines." May 1973. Table 19.
10	3	?	1.2, 2.2, 2.3 hp	UM	HC, CO, NO _x , CO ₂	Sun, X., et al., "Emissions Analysis of Small Utility Engines." SAE paper 952080. 1995.
11	1	11-year-old WBM*	2.4 hp	SwRI	HC, CO, NO _x , CO ₂ , PM, FC	Carroll, James N. Emission Tests of In-Use Small Utility Engines, Task III Report Non-Road Source Emission Factors SwRI 3426-006 for EPA, September 1991.
12	1	?	1.25 hp	UM	HC, CO, NO _x , CO ₂	Sun, X., et al., "Emissions Analysis of Small Utility Engines." SAE paper 952080. 1995.

13	24 including	handheld		Poulan/ Weed Eater	HC, CO, NO _x , FC	Liechty, Kim. "Investigation of In-Use Deterioration of Exhaust Emissions from Small Single-Cylinder Two Stroke-Cycle Engines," SAE 952137.
	3	blowers	0-1 hp			
	3	blowers	1-3 hp			
	6	trimmers	0-1 hp			
	3	chainsaws	0-1 hp			
	9	chainsaws	1-3 hp			
14	5	1-7-year-old handheld engines*	?	SwRI	HC, CO, NO _x	Carroll, J.N., J.J. White. "Emission Testing of In-Use Handheld Engines" SwRI 08-4855--211. (EPA Docket A-93-25//II-A-06).
15	3	string trimmers	0-1 hp	PPEM A	HC, CO, NO _x	"PPEMA/AQC In-Use Emissions Test Report: 25 cc String Trimmers." 1993. (Docket A-93-25//II-D-23, attach 2)
16	3	chainsaws	1.4 hp	PPEM A	HC, CO	EPA/PPEMA "In-Use" Emissions Test Report. (Docket A-93-25//II-D-23, attach. 3)
17	1	4-year-old string trimmer*	0.5 hp	SwRI	HC, CO, NO _x , CO ₂ , PM, FC	Carroll, James N. "Emission Tests of In-Use Small Utility Engines, Task III Report Non-Road Source Emission Factors" SwRI 3426-006 for EPA, September 1991.
18	1	string-trimmer	?	SwRI	HC, CO, NO _x , FC	J.P. Latusek and R.W. Burrahm, "Conversion of Two Small Utility Engines to LPG Fuel", 1993, SAE 932447. Note, data is from a 2-mode test.

*In-use testing listed for reference only. EPA does not plan to include this data when calculating emission factors for new engines.

4-Stroke Gasoline Engines

Table A4 lists references for data used for four-stroke gasoline engines in previous inventories and planned for the NONROAD beta model. The table also lists studies that provide additional data that EPA will consider when recalculating emission factors for the final version of the model.

Tables A5 and A6 describe the studies referenced in Table A4.

Table A4—Data Sources for Baseline Emission Factors for Four-Stroke Gasoline Engines

Equipment Description	Emission Factor Data Sources Used for:				Notes	Additional Data Sources
	NEVES	ARB	Small Engine Model	Nonroad Beta Version		
Off-Road Motorcycles, ATVs	A?	A	na	A	It is not clear where NEVES PM estimates are from, but we will use them for beta.	
Golf carts, Minibikes and Specialty Carts (>3 hp)	A	B	C	C	Operating at lower RPM, these are more like lawnmowers than motorcycles.	1
Snowmobiles	na	na	na	A	A few exist. We will use motorcycle factors.	
General (>25 hp)	D	C,E	na	D	See Table 1 in the main report.	2-5
General (<25 hp)	D	B	C	C		6-15
Lawn & Gard., Commercial, Logging, Airport Support (<25 hp)	C	B	C	C		6-15
Rec. Marine-- Outboards	F	F	na	F		16
Rec Marine-- Sterndrive/ Inboards	G	G*	na	G		17-18
Rec Marine-- PWC	na	na	na	na	No 4-strokes in baseline years	

* There may be a typographic error in ARB's emission factor for 4-stroke inboards.

Table A5—Emission Factors Data Sources Listed in Table A4 for Four-stroke Gasoline Engines

Reference Code	Number of Engines Tested	Age, design and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
A	?	?	?	?	HC, CO, NO _x	ARB Mailout #90-58, "Proposal to control emissions from Off-Road Motorcycles," September 7, 1990. (For NEVES, converted to g/hr based on an average speed of 25 mph).
B	"more than 500"	?	?	man.	HC, CO, NO _x	Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model, Energy and Environmental Analysis, Inc., for California Air Resources Board, February, 1997. Appendix A.
C	29 including 7 9 4 6 3	side-valve OHV side-valve OHV side-valve	3.5-5 hp 4-5 hp 8-12 hp 11-12.5 hp 16-18 hp	SwRI	HC, CO, NO _x (PM and FC for 6 engines)	Technical Support Document for California Exhaust Emission Standards and Test Procedures for 1994 and Subsequent Model-Year Utility and Lawn and Garden Equipment Engines. (ARB TSD) California Air Resources Board. Attachment C to ARB Mailout #90-64. December 1990. p. 31. Six of these engines are reported in SAE 910560, which lists PM and FC. <i>(Note that both NEVES and the Small Engine model use this data, but the emission factors are different because the calculations use different groupings. The Beta version of NONROAD will start with the emission factors from the small engine model, but will combine them into NONROAD categories using the sales fractions for OHV and Side Valve engines listed for "All Other Equipment" in Table B3 of Appendix B.)</i>

D	4	?	30-85	SwRI	HC, CO, NO _x , PM, FC	Hare, C.T and K.J. Springer. Exhaust Emission from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines, Final Report, Part 5, Heavy Duty Farm, Construction and Agricultural Engines. San Antonio TX: Southwest Research Institute, October 1973. (SwRI provided differently-weighted averages for various applications, creating a large number of emission factors from a few data points.)
C	2	?	53.5 and ?	?	HC, CO, NO _x	Cited in Regulatory Strategies for Off-Highway Equipment.” EEA for ARB, August 1992.
F	3	outboard engines	10-45 hp	NMM A	HC, CO, NO _x , BSFC	NEVES Table I-11b
G	3	sterndrive/ inboard engines	120- 200 hp	NMM A	HC, CO, NO _x , BSFC	NEVES Table I-11c

Table A6--Known Additional Data Sources Listed in Table A4 for Four-Stroke Gasoline Engines

Reference Code	Number of Engines. Tested	Age, design and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
1	1	OHV golf cart	8.4 hp	SwRI	HC, CO, NO _x , PM, BSFC	White, Jeff J. et al. "Baseline and Controlled Exhaust Emissions from Off-Highway Vehicle Engines," SAE 931541 (SwRI/ARB), December 1993.
2	3		106, 107, 109 hp	SwRI	HC, NO _x	Carroll, J.N. "Emission Tests of a 4.9 Liter Ford Utility Engine in Twelve Configurations", SwRI for Geometric Results, April 1994.
3	2	lift-trucks	41.4, 85 hp	SwRI	HC, CO, NO _x , PM, CO ₂ , FC	Carroll, James N. and J. J. White. "Final Letter Report "Emission Tests of Three Lift-Truck Engines". SwRI 08-53L to William Montweiler, Industrial Truck Association. February 10, 1993.
4	2	utility engines	60, 100 hp	SwRI	HC, CO, NO _x , PM, BSFC	White, Jeff J. et al. "Baseline and Controlled Exhaust Emissions from Off-Highway Vehicle Engines," SAE 931541 (SwRI/ARB) December, 1993.
5	5 (planned)	various applications	37- 205 hp	SwRI	HC, CO, NO _x , BSFC	White, Jeff J. et al. "Three-Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines, Interim Report" SwRI 8778 for CA ARB, December 1997.

6	3	side-valve WBM's, 1-10 years old*	3.5-5 hp	EPA	HC, CO, NO _x , other CO ₂ , other toxics and HC fractions	Gabele, Peter. "Emissions from 4-Cycle Walk-Behind-Mower Engines: Test Cycle Effects. SAE 972793.
7	8 including 6 2		1-5 hp 8-12.5 hp	UM	HC, CO, CO ₂ , NO _x	Sun, X., et al. "Emissions Analysis of Small Utility Engines" SAE paper 952080. Data on same engines reported in "Small Engine Emissions" in Off Highway Engineering, Dec. 1995.
8	45	1-16 year-old lawnmowers*	3-5 hp	Ctr. for Em. Res. Anal.	HC, CO, NO _x , CO ₂	Assessment of In-Use Emissions of Gasoline Engine Powered Lawnmowers, Final Report" The Center for Emissions Research and Analysis, Project #92-002 for EPA, etc., March 17, 1995
9	1	utility engine	8 hp	SwRI	HC, CO, NO _x , CO ₂ , FC	Burrahm, Robert W., Jeff J. White and James N. Carroll. "Small Utility Engine Emissions Reduction Using Automotive Technology." SAE paper 911805 in Two Stroke Engines, Small Engines and Emissions Reductions, SAE SP-883. Table 3.
10	1	riding mower	?	?	CO, HC+ NO _x	Swanson, Mark. "An Emission Comparison Between a Carburetor and an Electronic Fuel Injection System for Utility Engines." SAE paper 911806 in SAE SP-883. Table 2.
11	3	2 lawnmowers, 1 utility engine	4.5, 5, 11 hp	SwRI	HC, CO, NO _x , CO ₂ , FC	White, Jeff J. et al. "Emission Control Strategies for Small Utility Engines," SAE paper 911807 in SAE SP-883. Table 7, 9,10.

12	4	?	?	3.5, 4, 12.5, 18 hp	SwRI	HC, CO, NO _x , PM	Hare, C.T., and Karl Springer. "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines, Final Report, Part 4, Small Air-Cooled Spark Ignition Utility Engines." May 1973.
13	?	?*	?	?	Onan		Fax from Onan Corporation: "OPEI In-Use Emissions Testing." Docket A-93-25/II-D-46.
14	1	OHV WBM	OHV	3.5 hp	SwRI	NMHC, CO, NO _x , PM	Hare, C.T., and J.J. White. "Toward the Environmentally-Friendly Small Engine: Fuel, Lubricant, and Emission Measurement Issues," 1991. SAE 911222.
15	1	OHV	OHV	(435 cc)	SwRI	?	Energy and Environmental Analysis, Inc. "Regulatory Strategies for Off-Highway Equipment," August, 1992.
16	1	outboard marine engine	outboard marine engine	8 hp	EPA	HC, CO, NO _x , FC	"Memorandum: Exhaust Emission Testing of a Two-Stroke and a Four-Stroke Marine Engine; Results and Procedures," Mike Samulski to Docket #A-92-28, May 30, 1996.
17	4	inboard marine engines	inboard marine engines	?	EPA	HC, CO, NO _x , FC	"Memorandum: Effects of Transience on Emissions from Inboard Marine Engines," from Michael Samulski, to Docket #A-92-28. May 30, 1996. (Note: includes data from Samulski, M., "Sensitivity of Test Cycle and Fuel Type on a Spark-Ignition Four-Stroke Inboard Marine Engine," 1994. SAE 941782.)
18	1	sterndrive marine engine	sterndrive marine engine	?	Mich. Auto. Res. Corp.	HC, CO, NO _x , FC	"A Comparison of Exhaust Emissions on a Marine Engine Run on Steady State and Simulated Transient Cycles," Michigan Automotive Research Corporation for National Marine Manufacturers Association, October 8, 1992.

*In-use data listed for reference only. EPA does not plan to include this data when calculating emission factors for new engines.

Other Spark Ignition Engines

Table A7–Data Sources for Baseline Emission Factors for CNG/LPG engines

Equipment Description	Emission Factor Data Sources Used for:			Notes	Additional Data Sources
	NEVES	ARB	Nonroad Beta Version		
All CNG/LPG Equipment	A,B	C,D	A,B	NEVES created emission factors by multiplying the relevant gasoline factor by an adjustment factor. The beta version of NONROAD will use the NEVE emission factor.	1-5

Table A8–Emission Factors Data Sources Listed in Table A7 for Natural Gas/LPG Engines

Reference Code	Number of Engines Tested	Age, design and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
A	1			SwRI	HC, CO, NO _x , PM	J.J. White, et. al. "Emission Factors for Small Utility Engines," 1991. SAE 910560
B	1			Onan	HC, CO, NO _x	Williamson, Dale E. Onan Corporation. Letter to California Air Resources Board, July 20, 1990.
C	?	?	?	man.	HC, CO, NO _x	Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model, Energy and Environmental Analysis, Inc., for California Air Resources Board, February, 1997. Appendix A.
D	1	utility engine	? (400 cc)	Walbro	HC, CO, NO _x , BSFC	"A Study of the Potential of Propane Fuel to Reduce Utility Engine Exhaust Emissions," Kenneth J. Cotton, Walbro Engine Management Corp. SAE 921696, September, 1992.

Table A9--Known Additional Data Sources Listed in Table A7 for Natural Gas/LPG Engines

Reference Code	Number of Engines Tested	Age, design and Application of Engines	Horse-power of engine	Testing lab	Emissions measured	Citation and notes
1	2	lift truck, utility engine	40, 60 hp	SwRI	HC, CO, NO _x , PM, BSFC	White, Jeff J. et al. "Baseline and Controlled Exhaust Emissions from Off-Highway Vehicle Engines," SAE 931541 (SwRI/ARB 1993) December 1993. (Note, while ARB sponsored these tests, they chose not to use the data because the engines were tested at very lean calibrations.)
2	1	2s trimmer 4s side-valve	?	SwRI	HC, CO, BSFC	J.P. Latusek and R.W. Burrahm, "Conversion of Two Small Utility Engines to LPG Fuel," 1993, SAE 932447.
3	1	lift truck	85 hp	SwRI	HC, CO, NO _x , CO ₂ , BSFC	Carroll, James N. and J. J. White. "Final Letter Report: Emission Tests of Three Lift-Truck Engines". SwRI 08-53L to William Montweiler, Industrial Truck Association. February 10, 1993.
4	1		102 hp	SwRI	HC, NO _x	Carroll, J.N. "Emission Tests of a 4.9 Liter Ford Utility Engine in Twelve Configurations", SwRI for Geometric Results, April 1994.
5	4 (planned)	various	37-53 hp	SwRI	HC, NO _x , CO, BSFC	White, Jeff J. et al. "Three-Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines, Interim Report" SwRI 8778 for ARB, December 1997.

Appendix B

Cross-Inventory Comparison of SI Emission Factors

The body of Appendix B is the large Microsoft Excel™ spreadsheet *compare.xls*. This document explains how the spreadsheet was created and explains how to use the spreadsheet, which compares emission factors from NEVES, OFF-ROAD, EPA's Small Engine Model and the beta version of NONROAD.

To make it possible to compare emission factors for specific equipment types, the rows in the spreadsheet *compare.xls* are a list of every combination of Source Classification Code (SCC) and horsepower group for spark ignition engines. The rows include SCCs (including 2266xxxxx and airport service equipment) that are not used in NONROAD but are used by California Air Resources Board (ARB). The columns in the spreadsheet are emission factors from NEVES, from ARB's draft OFF ROAD model, and from the Small Engine model. These are followed by some notes on differences between the factors and by a list of the emission factors used in the Beta version of NONROAD. Various subsets of the spreadsheet's columns can be selected by choosing "View Manager"™ in Excel's "View" menu.

Comparing emission factors between inventory models is not straightforward because the different models and inventories use different units and different categories in distinguishing emission factors. To compare the factors, all factors were converted to list emission factors in g/hp-hr by engine type, application and horsepower. This conversion required mapping both the ARB horsepower groups and the Small Engine Model's displacement classes to the horsepower groups used by the NONROAD model (see Tables B-1 and B-2). It was also necessary to combine the Small Engine Model's overhead-valve and side-valve categories into a single category by using a sales-weighted average, using the sales mix listed in Table B-3.

Note that the BSFC column labeled as NEVES BSFC is not directly from NEVES, but is based on NEVES information. Also note that the input files for NONROAD will have fewer entries because, without the need to compare across models and inventories, emission factors will be grouped by global SCCs and larger horsepower ranges.

Table B1--Mapping of small engine groupings used in the Small Engine Model and ARB's OFF-ROAD model to the small engine groupings used in the NONROAD model

Small Engine Model Class/Displacement	ARB Power Range	NONROAD Power Range	NONROAD source classification
Non-Handheld, I <225 cc	2-5 hp	3-6 hp	All engines except 2-stroke trimmers/edgers/cutters, chainsaws, leafblowers, and snowblowers
Non-Handheld, II >225 cc	5-15 hp 15-25 hp	6-16 hp 16-25 hp	All engines except 2-stroke trimmers/edgers/cutters, chainsaws, leafblowers, and snowblowers
Handheld, III 0-20 cc	≤ 2 hp	0-1 hp	All engines
Handheld, IV 20-50 cc	≤ 2 hp	1-3 hp	All engines
Handheld, V >50 cc	2-15 hp	3-6 hp	All 2-stroke trimmers/edgers/cutters, chainsaws, leafblowers, and snowblowers

Table B2-- Mapping of large engine groupings used in ARB's OFF-ROAD model to the large engine groupings used in the NONROAD model.

ARB hp range	NONROAD hp Range
5-15	6-11 & 11-16
15-25	16-25
25-50	25-50
50-120	50-100
120-175	100-175
175-250	175-250
250-500	250-500
500-750	500-750
750-9999	750-3000+

Table B3--Sales Mix for Small Engine Model, Pre-control [1]

Application	Sales Mix									
	2-stroke handheld			2-stroke non-handheld		4-stroke non-handheld, overhead- and side-valve				
	Class 3	Class 4	Class 5	Class 1	Class 2	Class 1 OHV	Class 1 SV	Class 1 OHV	Class 2 SV	
Lawn Mowers				0.1		0.065	0.835		0.0014	
Trimmers/Edgers/ Cutters	0.0501	0.9173	0.0077			0.0016	0.0231		0.0002	
Chain Saws	0.0035	0.6426	0.3539							
Leaf Blowers/Vacuums	0.0528	0.6299	0.2086			0.0007	0.0721	0.0001	0.0359	
Generator Sets				0.0017		0.0057	0.2853	0.0551	0.6522	
Tillers		0.0101	0				0.7938	0.0001	0.196	
Snowblowers			0.3205				0.3732		0.3063	
Commercial Turf Equipment				0.0099		0.04	0.0647	0.3658	0.5196	
Rear Engine Riding Mowers							0.0499	0.1563	0.7939	
Lawn & Garden Tractors						0.0222	0.804	0.0013	0.1725	
Pumps							0.0049	0.1421	0.8531	
All Other Equipment				0.0974	0.0024	0.0375	0.4064	0.0081	0.4482	

[1]*Documentation of the OMS Small Gasoline Engine Spreadsheet System, Final Technical Memorandum” TRC Environmental Corporation for U.S. EPA Air and Energy Research Laboratory. August 1995.

Appendix C Technology Groups

NONROAD accounts for changes in sales fractions and emissions from the advent of emission standards or other changes by assigning technology groups to each Source Classification Code (SCC). Each technology group has its own emission factor and the fraction of the population assigned to each group can change over time. These “technology fractions” are contained in an input file in NONROAD called *tech.dat*. A sample record for 4-stroke lawnmowers might show a shift in engine sales from side-valve engines (Tech Group 1) to overhead valve engines (Tech Group 2) as illustrated in Table C1, which shows side-valve engines declining from 90% of sales in 1991 to 50% of sales in 1997.

Table C1: Sample Technology Fractions

SCC/Year	Horsepower Range	Tech group/fraction	Tech group/fraction
2260004010	3-6 hp	1	2
1990		0.90	0.10
1997		0.50	0.50

Each technology group has an associated emission factor given in the emission factor input file for that pollutant. This emission factor can change with time. For example, CO emissions from Technology Group 1 (side-valve engines) might decrease from 819 g/hp-hr for model year engines 1990 through 1996 to 387 g/hp-hr for model years 1997 and later as shown in Table C2. The year listed in the emission factor input file is the first year in which the new emission factor applies.

Table C2: Sample Emission Factors

SCC/Year	Horsepower Range	Technology group/emissions	Units	Pollutant
2265004010	3-6 hp	1	g/hp-hr	CO
1990		819		
2265004010	3-6 hp	1	g/hp-hr	CO
1997		387		

For pre-controlled engines the only technology groups currently identified are those used to combine SCCs for spark-ignition engines <25 hp as described in NR-006. Technology groups primarily will be used for engines subject to emissions regulations. The regulations discussed in the main body of this report are expected to influence the sales fraction of various technology

types and the emission rates of those technologies. These anticipated changes are described in EPA's rulemakings and set forth in the spreadsheets *Tech1.wk4*, *Techmix.wk4*, and Appendix F of the small engine Phase II regulatory support document. The emission factors for Phase I and Phase II engines are listed as "new engine exhaust" values in Table F-07. The expected sales mixes for Phase I and Phase II as listed in Tables F-03 and F-04 of the RSD appendix.[1] For both the beta and final versions of NONROAD, EPA will simply format this information for the NONROAD input files.

If new emission factors are developed for other parts of the inventory (e.g., larger SI engines) to reflect distinctions between different engine technologies with different emission levels, then appropriate technology groups, technology fractions, and emission factors will be added to the model. Similarly, appropriate emission factors will be added to the model if new emission standards are implemented.

References

[1] "Regulatory Support Document, Phase 2: Emission Standards for New Nonroad Spark Ignition Engines At or Below 19 Kilowatts". U.S. EPA, Office of Air and Radiation, December 1997.